Flight Data Analysis Report

George Gee
SGT-Inc.

Christian Poivey
SGT-Inc.

Harvey Safren
NASA-GSFC

July 1, 2003

Table of Contents

1 Introduction

The objectives of this study are:

- to assess and evaluate the in-flight radiation induced performance of new and emerging microelectronics and photonics devices.
- To correlate engineering results obtained from this task to the space environment.

The program and equipment analyzed are:

- SEASTAR : Flight Data Recorders.
- XTE : Flight Data Recorders and 1773 Fiber Optics Data Bus.

This report presents the analysis results for the period from July 2002 to September 2002. Previous results have been presented in at the IMAPS [1] and SEE [2, 3] conferences and in the previous quarterly reports [4 to 14].

2 SEASTAR/Orbview-2

2.1 Description

- Observed equipment: Flight data recorders (FDR1&2) from Seakr Solid State Recorders (SSR) with 64 Mbytes of memory.
- Technology :
    - Error Detection and Correction (EDAC) (16,22) Modified Hamming Code- single bit correct, double bit detect.
    - Telemetry gathered at 10 seconds intervals- Watchdog timer w/ soft reset, 1 second timeout.
    - COTS DRAM HITACHI MDM1400G-120, 4 Mx1 bit, 220 DRAM per FDR.
    - MOSAIC semiconductor repackaged the die. Lot date codes of packaging are 9202,9147,9335.
- Mission:
    - Altitude: 705-705 km
    - Inclination: 98.2°
    - Launched in 1997

2.2 Summary of previous results

The previous analysis [1 to 14] covered the period from 1/1/1999 to 1/12/2003. The data showed a general decrease of the upset rate. The data also showed a very high upset rate during the July 14th 2000 and November 9th 2000 solar events. On April 15, 2001; September 25, 2001; November 5 and 6, 2001; April 21, 2002; and August 24, 2002 solar events, high upset rates were also observed, but these solar event were of lower magnitude than the July and November 2000 solar events. They led to a lower increase of the upset rate.

2.3 Results

The new data cover the period from 9/22/2002 to 4/6/2003. The following results and analysis will be presented in the NSREC2003 data workshop . Fig 1 shows in a world map the distribution of upsets accumulated from January 1999 to April 2003 in both Orbview-2's SSR. We can see a high density of trapped proton induced upsets in the South Atlantic Anomaly (SAA) where the spacecraft spends less than 20% of its orbit time. More than 80% of the SEU occur within the SAA. The Galactic Cosmic Rays (GCR) and solar particle induced upsets are spread over the high latitude regions of the orbit with a much lower density.

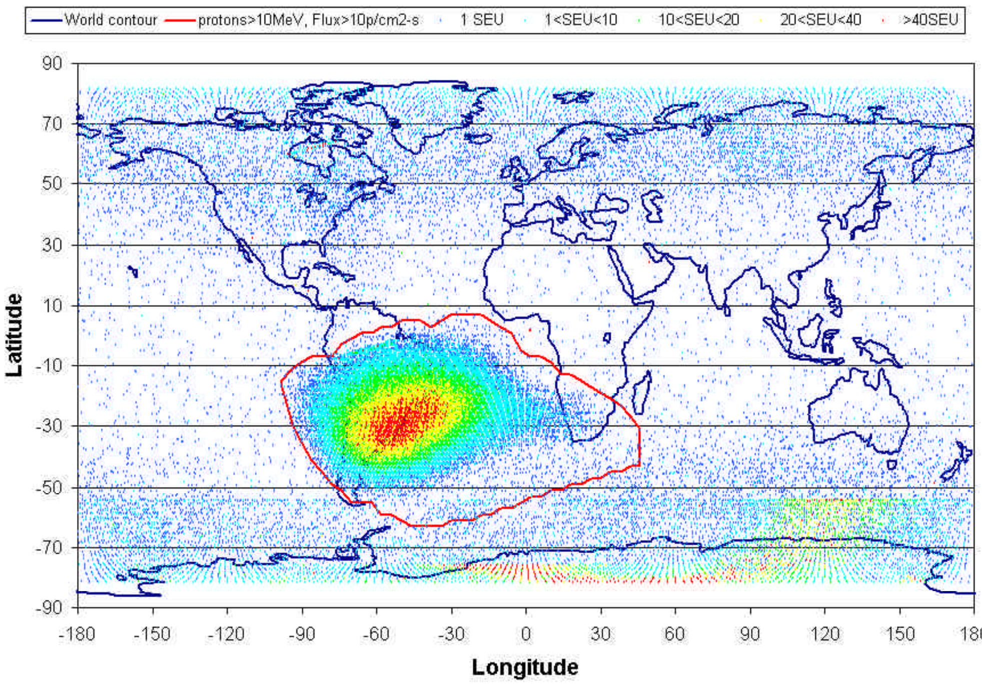

Fig 1:Number of errors per cell area of 4000 km^2. Data collected on both Orbview-2 SSR from January 1, 1999 to April 6, 2003.

Fig 2 shows the daily upset count for both SSR. We can see a day-to-day variation of +/-30%. On the following days, significantly higher upset counts were observed: July 14 and 15, 2000, November 9, 2000, April 15, 2001, September 25, 2001 November 4, 5, and 6, 2001, April 21, 2002, and August 24, 2002. These high upset counts correspond to the largest Solar Particle Events (SPE) observed during this period and are well correlated with the increased solar protons fluxes as measured by the GOES spacecraft and shown in Fig 3.

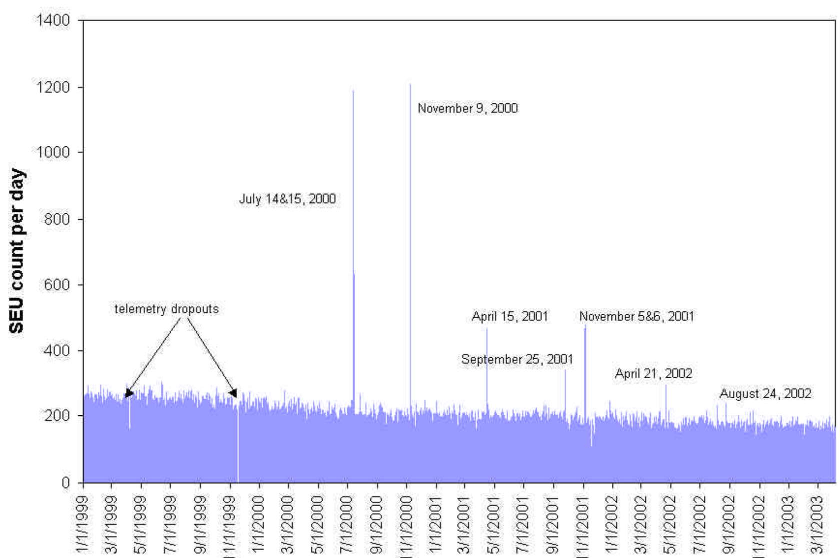

Fig 2: Daily upset count for both Orbview-2 SSR from January 1, 1999 to April 6, 2003.

We can also see in Fig 2, a general decrease of the upset count with time. This decrease is more visible in Fig 4 that shows the monthly averages of the daily upset numbers. Beginning of January 1999, the average SEU count per day was about 255, the first months of 2003, the average SEU count per day is about 170. The sunspot numbers plotted in Fig 4 show that we are at the maximum of the current solar cycle and that the SEU numbers decrease with the increasing solar activity.

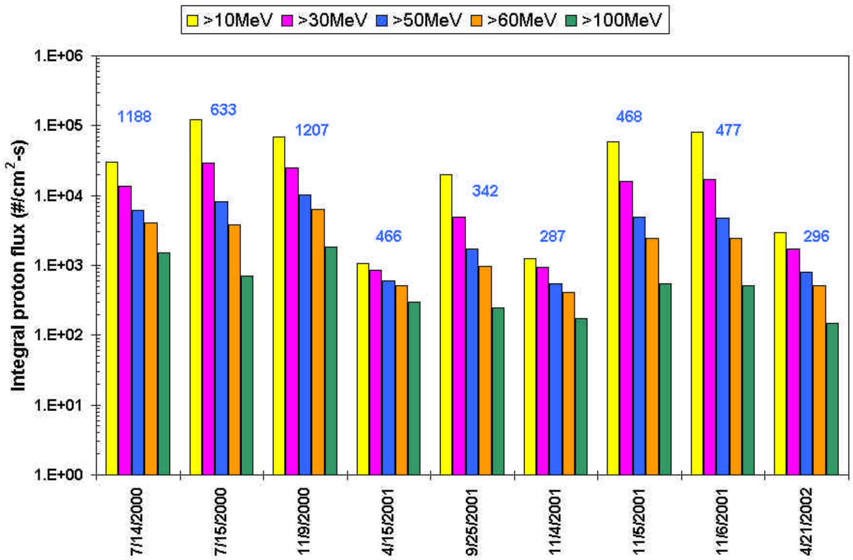

Fig 3: Solar proton flux spectra the days of the largest increased SEU counts. Data taken from GOES spacecraft, daily averages. NOAA Space Physics Interactive Data Resource (SPIDR) archives in http://spidr.ngdc.noaa.gov

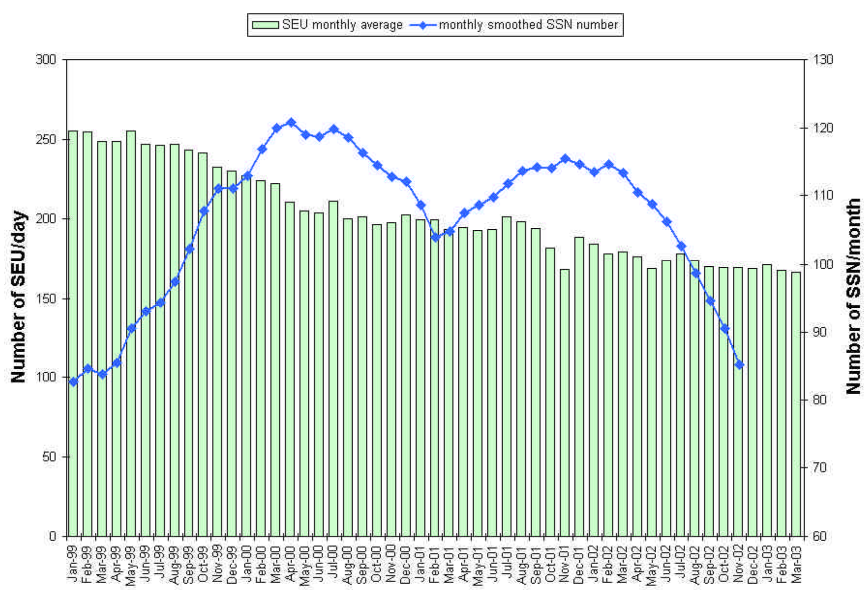

Fig 4: Monthly averages of daily upset counts (excluding solar event days and days with large telemetry dropouts) for both Orbview-2 SSR from January 1, 1999 to April 6, 2003 and monthly smoothed solar spot numbers. Sunspot numbers taken from Solar Influences Data analysis Center (SIDC) archives in http://sidc.oma.be

About 10% of the telemetry files showing SEU indicate that multiple upsets occurred during the 10s telemetry gathering period. The probability of concurrent upsets from multiple particles occurring during such a short period of time is quasi negligible. Therefore, we may assume that these multiple events are due to a single particle. The Flight data show that both protons and heavy ions can create these multiple events. Most of multiple upsets affect two or three memory cells. However, larger multiple upsets that could affect up to 30 memory cells were observed. These large multiple upsets were only observed in the high latitude regions of the spacecraft's orbit. Therefore, we assume that they were due to high LET cosmic rays or solar ions. We can see these large multiple events in figure 2 where there are high upsets density regions outside the SAA. In that case, the high upset density is not due to the accumulation over time of SEU but is due to the occurrence of large multiple upsets in these regions. Note that these multiple upsets occur in functionally different data structures because of the SSR memory devices one bit organization. These multiple events do not have any impact on the EDAC performances.

2.4 Comparison of actual SEU rates to predictions based on ground test data

The heavy ion ground test data was taken on the flight lot (date code 9147) [19]. Proton ground test data on other lots than the flight lot were found in the literature [5, 20]. Predictions were performed with CREME 96 using a Weibull fit of test data and assuming a 4 μm thickness of sensitive volume, and 100 mils Aluminum shielding thickness. Weibull fitting parameters used for the predictions are presented in Table 1.

Weibull fit parameters	**Heavy ion cross section**	**Proton cross section**
Onset	1.7 MeVcm^2/mg	18 MeV
Width	5 MeVcm^2/mg	20 MeV
Power	1	1
Plateau	13 μm^2/bit	0.064 10^{-12} cm^2/bit

Table 1: cross section data fitting parameters used for the predictions.

Solar minimum and Solar maximum models were used for the background environment (trapped protons and GCR). For the SEU rates during a Solar Particle event, we used the CREME 96 worst day model. Results are shown in Table 2.

	Calculated SEU rate both SSR (SEU/day)	Actual SEU rate both SSR (SEU/day)	Comments
Background environment	938 (solmin) 447 (solmax)	167 - 255	Min and max monthly averages
Solar Particle Event	291000	~1000	July 14, 2000
		~ 400	July 15, 2000
		~1000	November 9, 2000
		~ 280	April 15, 2001
		~ 300	November 5, 2001
		~ 300	November 6, 2001

Table 2: Comparison of actual SEU rates with predictions.

We can see in Table 2 that the calculated SEU rate using the solar minimum models overestimates by a factor four to six the actual SEU rates due to the background environment. Using solar minimum conditions is considered as a worst-case approach because trapped particle fluxes and cosmic ray fluxes are maximum during solar minimum. On the other hand, solar maximum conditions are considered as a best case. And, as about 80% of the SEUs occur in the SAA, we expected an underestimation of the SEU rate, because the AP8 model underestimates the actual trapped protons fluxes at low altitude. We can see in table 2 that the calculated SEU rate with the solar maximum models rate overestimates by a factor two to three the actual SEU rates. This overestimation may be due to different factors: conservative SEU characterization, conservative shielding assumptions, and conservative sensitive volume thickness assumptions. However, a factor two to six overestimation, depending on the solar conditions considered, can be considered as a reasonable agreement. Because flight data was collected during solar maximum conditions, the solar maximum prediction gives a closer estimation

Predicted SPE rate overestimates the actual rates during the largest events by two to three orders of magnitude. CREME96 SPE worst day model gives a worst-case estimation of the Solar Particle fluxes based on the October 1989 solar event; therefore, an overestimation was expected. SPE are hugely variable in intensity, spectral hardness and composition. However, such a large overestimation was not expected because the largest events observed equal in ions and exceed in protons the CREME96 worst day model [21]. Fig 5 compares the CREME 96 worst day incident integral proton flux with the incident proton fluxes measured by GOES during the large solar events. We can see that the largest events of July 14, 2000 and November 9, 2000 are very close to the CREME 96 worst day model.

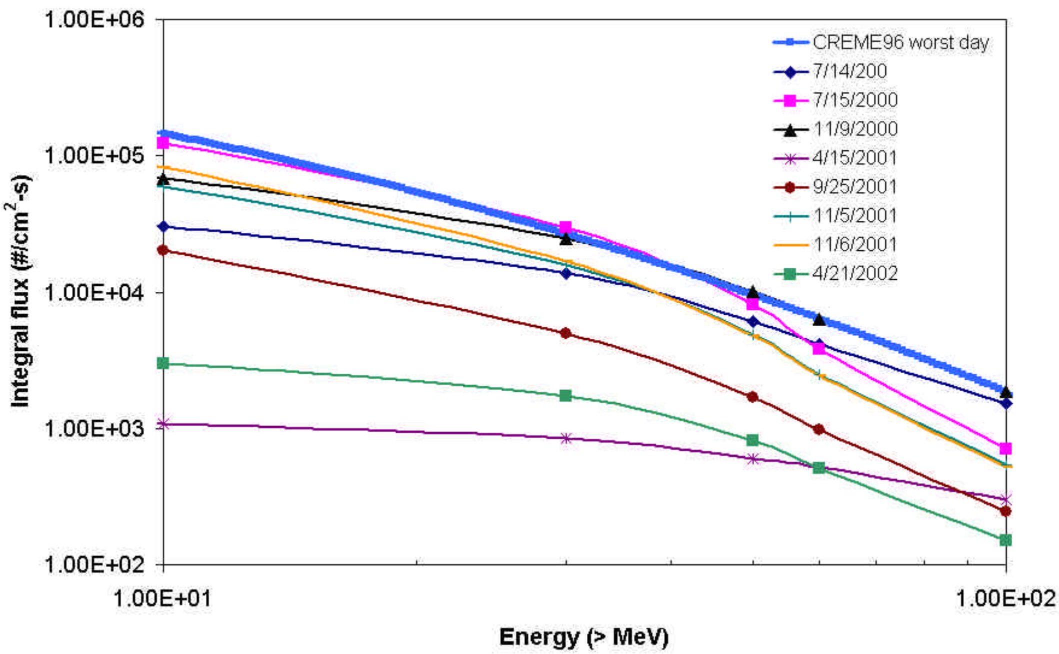

Fig 5: Integral solar proton fluxes measured by GOES during the largest solar events and comparison with the CREME96 worst day model (GEO orbit, incident flux).

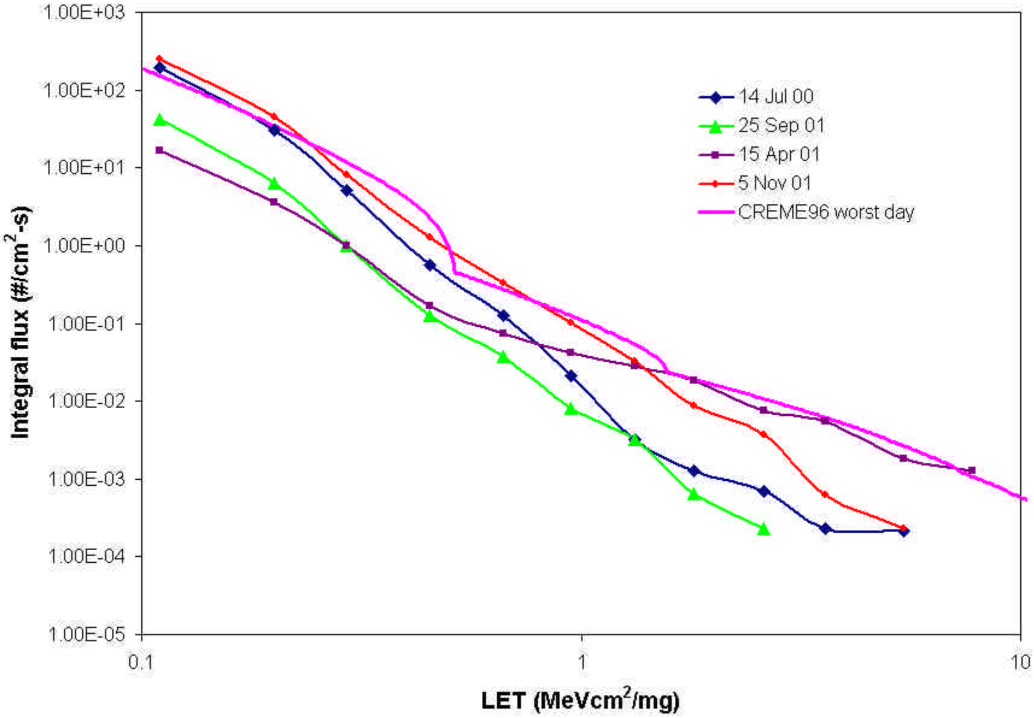

Fig 6: Integral LET spectra measured with the CREDO3 instrument flying on MPTB [21] and comparison with CREME96 worst day model (MPTB orbit, 6mm of shielding).

Fig 6 compares the LET spectra of the worst day of the major SPE with the CREME 96 model. We can see that at low LET, LET<1MeVcm^2/mg, July 14,2000 and November 5, 2001 are very close to the model. For LET> 1 MeVcm^2/mg, the April 15, 2001 is close to the model.

If we look at Fig 3, we can see that only the high energy protons have an impact on the SEU numbers during SPE. For example the proton >30 MeV and > 50 MeV fluxes are larger on July 15,2000 than on July 14, 2000. However, the SEU count on July 14 is twice the SEU count on July 15. On September 2001 the proton>60 MeV fluxes are significantly higher than the same fluxes on April 15, 2001, but the SEU count on April 15, 2001 is higher. Fig 7 compares the SEU count increases during the largest SPE with the >100 MeV proton flux these days. We can see the excellent correlation. As a the proton energy threshold is about 20 MeV, this indicates a thicker shielding thickness than the assumed 100 mils.

We have calculated an “equivalent” shielding thickness of 1440 mils. Table 3 gives the calculated rates with this shielding thickness.

	Calculated SEU rate both SSR (SEU/day)	Actual SEU rate both SSR (SEU/day)	Comments
Background environment	414 (solmin) 238 (solmax)	167 - 255	Min and max monthly averages
Solar Particle Event	2760	~1000	July 14, 2000
		~ 400	July 15, 2000
		~1000	November 9, 2000
		~ 280	April 15, 2001
		~ 300	November 5, 2001
		~ 300	November 6, 2001

Table 3: calculated rates with a 1440 mils shielding thickness.

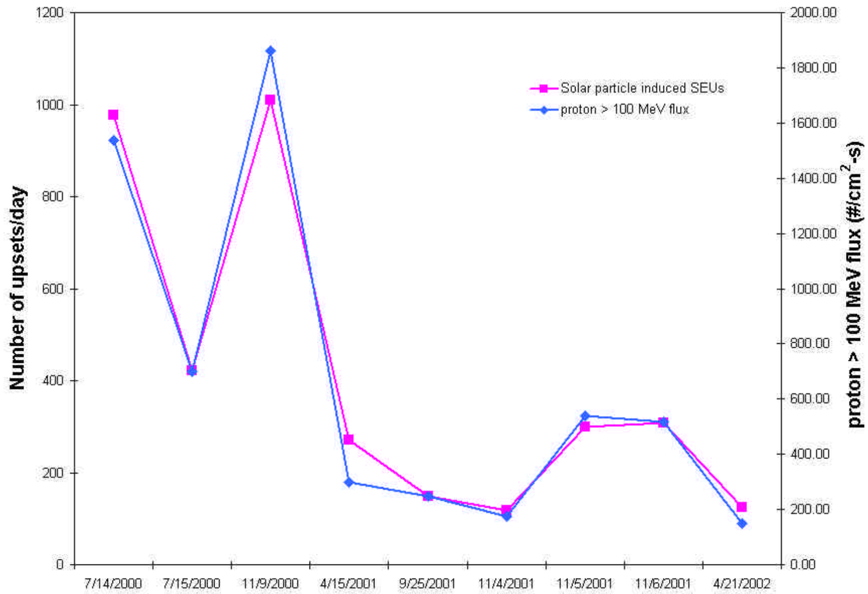

Fig 7: Comparison of the solar particle induced SEUs with the >100 MeV proton fluxes.

With this more realistic shielding thickness the SPE rate is reduced by 2 orders of magnitude, and the calculated rate overestimates the actual rates by a factor 3 to 10.

The background environment rates are also reduced by a factor 2, and now the solmax prediction is very close to the actual upset rates. Fig 8 compares the calculated rates for the background environment with the actual monthly average rates. The ratio predicted solmax to the actual rates varies from 0.9 to 1.4. In addition to the best case (solmax) and worst case (solmin) GCR flux models, CREME96 provides a model of solar modulation of GCR fluxes. We have calculated the SEU for the beginning of each year from 1999 to 2003. The results are shown in Fig 8 (sky blue curve). The predicted rate beginning of 1999 is 333 SEU/day; the predicted rate beginning of 2003 is 253 SEU/day. We can see that the modulated rates follow the trend of the actual data even though the decrease is lower because CREME96 does not provide a modulation for the trapped proton fluxes.

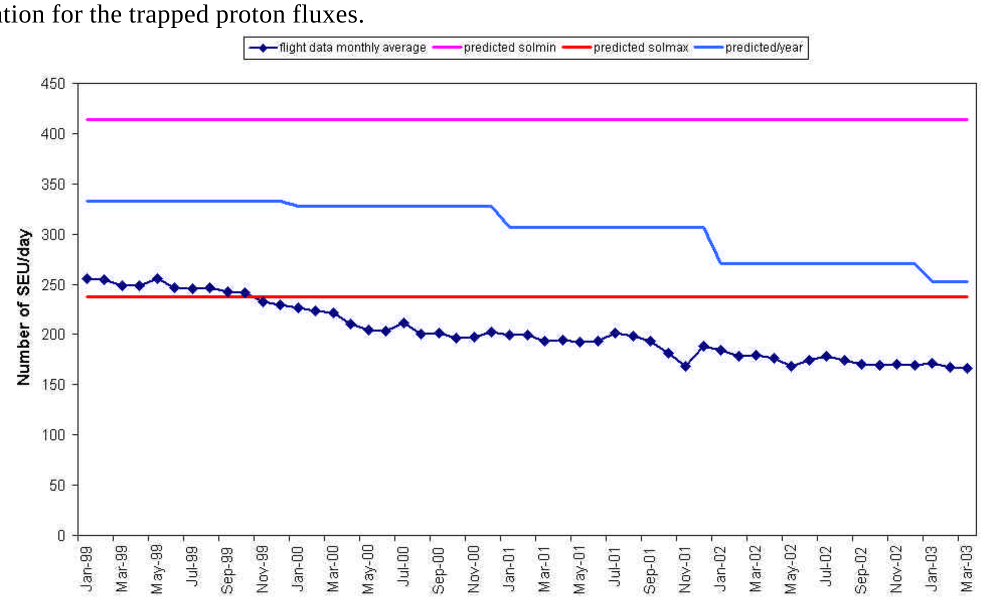

Fig 8: predicted rates and actual rates, background environment, 1440 mils of shielding.

2.5 Performance of the SEE mitigation method

Flight data shows that about 10% of the events are multiple events. These multiple upsets occur in functionally different data structures because of the SSR memory devices one bit organization. Therefore, these multiple events do not have any impact on the EDAC performances.

The EDAC Hamming code will fail if the same data structure is hit in two separate devices due to coincidental but independent events. This probability is kept small if the memory is scrubbed at a sufficiently rapid rate. In this kind of orbit it is not a good statistics to calculate the probability of failure on the basis of daily averaged SEU rates. We have seen that the large majority of SEUs, more than 80%, occur only within the South Atlantic Anomaly in bursts lasting less than 20 minutes each orbit. Thus, the trapped protons give a very high SEU rate that increases the probability of failure. Fig 9 shows the probability of failure versus the scrubbing period. We have calculated a 5 years probability of mission failure bases on the peak rates observed on the SAA and on the orbit averaged rates. The probability to have one EDAC failure during a 5 years mission is about 0.2 based on the peak rates for the 16 minutes scrubbing period. We can see in Figure 9 that the probability of failure based on the orbit averaged rates is one order of magnitude lower. We have also calculated the probability of failure during a large solar event day; the probability is negligible. These calculations are consistent with the in flight observations where no science data were lost.

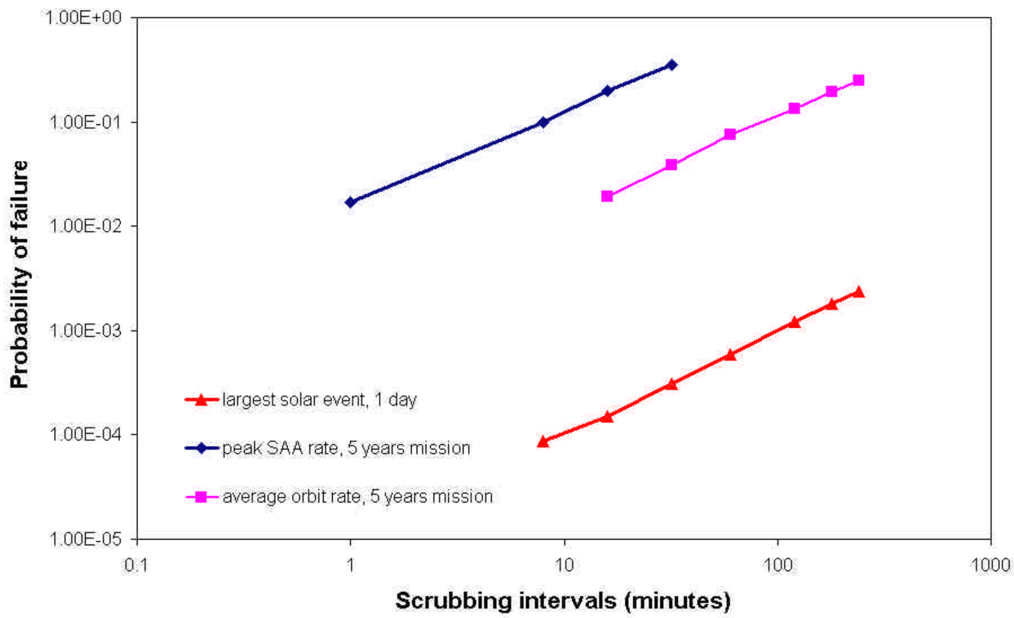

Fig 9: probability of failure versus the scrubbing interval.

2.6 Work planned for the next period

The following work is planned:

- Continuation of new data analysis.

3 XTE

3.1 Description

- Observed equipment:
    - Solid State Recorders (SSR) with 140 Mbytes of memory.
    - MIL-STD1773 FODB.
- Technology :
    - SSR

    - Error Detection and Correction (EDAC) (8,32) Hamming Code- single bit corrects, double bit detect.
    - Redundant unit available on board.
    - COTS SRAM HITACHI HM628128, 128Kx8 bit.
    - Ground test data published previously, sensitive to Single Event Upset (SEU), some sensitivity to Multiple Bit Upsets (MBU) and slight sensitivity to Single Event Latch-up (SEL).
  - FODB
    - 100/140 μm Brand Rex Pure Glass Fiber (Corning SDF)
    - Si PIN photodiodes receivers.
    - AlGaAs LED transmitters.
    - Bendix connectors.
    - 850 nm operating wavelength.
- Mission:
  - Orbit: Circular originally at 580 km, but losing altitude (530 km in January 2002).
  - Inclination: 23°
  - Launched in 1996.

3.2 Summary of previous results

The previous analysis [1,2,4-14] covered the period from July 1996 to March 13, 2003. The way the memories are checked does not allow knowing exactly the spacecraft position when the errors have occurred. But, the SEU rate tracks with the orbital altitude decay: as the altitude decreases, the upset rate decreases. This is consistent with a lower SAA proton exposure. MBU have occurred resulting in some data loss. This data loss has been acceptable for the mission. . No effect of the solar events has been observed.

3.3 Results

No new data was available for analysis this quarter.

3.4 Work planned for the next period

The following work is planned:

- Continuation of new data analysis.

4 Reference Documents

1 “Flight Engineering Data Results” presented at IMAPS, May 2000.
2 “In Flight Data Analysis” presented at SEE conference, April 2000.
3 “SEU analysis of SEASTAR and the MAP anomaly” presented at SEE conference, April 2002.
4 “Flight data analysis report”, October 2000.
5 “Flight data analysis report”, January 2001.
6 “Flight data analysis report”, April 2001.
7 “Flight data analysis report”, July 2001.
8 “Flight data analysis report”, October 2001.
9 “Flight data analysis report,” January 2002.
10 “Flight data analysis report,” April 2002.
11 “Flight data analysis report,” July 2002.
12 “Flight data analysis report,” October 2002.
13 “Flight data analysis report,” January 2003.
14 “Flight data analysis report,” April 2003.
15 World Data Center for the Sunspot Index web site : http://sidc.oma.be
16 Space Physics Interactive Data Resources web site : http://spidr.ngdc.noaa.gov